

### Claims

What is claimed is:

1. A processor-implemented method of scheduling data packets for transmission over a communication link in a network, the method comprising the steps of:

5                    computing delay measures for a plurality of packets including at least one packet from each of a plurality of queues; and

                  selecting a given one of the plurality of packets for transmission based at least in part on a comparison of weighted versions of the computed delay measures, such that the selected packet is the packet having the largest weighted delay associated therewith.

10                   2. The method of claim 1 wherein the step of computing delay measures for a plurality of packets includes computing the delay measure for a given one of the packets as a difference between a current time and an arrival time of the given packet in a node of the communication network.

15                   3. The method of claim 1 wherein the plurality of packets comprise  $N$  packets, each associated with a corresponding one of  $N$  data flows and located in a head position in a corresponding one of  $N$  queues.

20                   4. The method of claim 3 wherein the selecting step includes selecting a packet from a head position of a  $j$ th one of the  $N$  queues, such that a function of a given weight  $\alpha_j$  and a given delay measure  $W_j$  is maximal among all such functions for  $j = 1, 2, \dots, N$ , where  $\alpha_j$  is one of a set of positive weights  $\alpha_1, \alpha_2, \dots, \alpha_N$ .

25                   5. The method of claim 4 wherein the function of the given weight and the given delay measure is  $W_j/\alpha_j$ .

6. The method of claim 4 wherein the computing and selecting steps are configured to meet a quality of service requirement specified in terms of a deadline  $T_i$  and an allowed deadline violation probability  $\delta_i$ .

7. The method of claim 6 wherein each of the weights  $\alpha_i$  in the set of positive weights  $\alpha_1, \alpha_2, \dots, \alpha_N$  is given by  $\alpha_i = -T_i / \log \delta_i$ .

8. The method of claim 6 wherein the quality of service requirement is specified by:

$$P(W_i > T_i) \leq \delta_i \quad \text{for } i = 1, \dots, N.$$

9. The method of claim 3 wherein the selecting step includes selecting a packet from a head position of a  $j$ th one of the  $N$  queues, such that a function of a given weight  $\alpha_j$  and a given delay measure  $Q_j$  is maximal among all such functions for  $j = 1, 2, \dots, N$ , where  $\alpha_j$  is one of a set of positive weights  $\alpha_1, \alpha_2, \dots, \alpha_N$ , and  $Q_j$  is a queue length of the  $j$ th queue.

10. The method of claim 9 wherein the function of the given weight and the given delay measure is  $Q_j / \alpha_j$ .

11. The method of claim 10 wherein the computing and selecting steps are configured to meet a quality of service requirement specified in terms of a maximum queue length  $H_i$  and an allowed queue length violation probability  $\delta_i$ .

12. The method of claim 11 wherein each of the weights  $\alpha_i$  in the set of positive weights  $\alpha_1, \alpha_2, \dots, \alpha_N$  is given by  $\alpha_i = -H_i / \log \delta_i$ .

13. The method of claim 11 wherein the quality of service requirement is specified by:

$$P(Q_i > H_i) \leq \delta_i \quad \text{for } i = 1, \dots, N.$$

14. An apparatus for use in scheduling data packets for transmission over a communication link in a network, the apparatus comprising:

a set of queues, each of at least a subset of the queues including at least one packet;

and

a link scheduler having inputs coupled to corresponding outputs of the queues, the link scheduler being operative to compute delay measures for a plurality of packets including at least one packet from each of the at least a subset of the queues, and to select a given one of the plurality of packets for transmission based at least in part on a comparison of weighted versions of the computed delay measures, such that the selected packet is the packet having the largest weighted delay associated therewith.

15. The apparatus of 14 wherein the link scheduler is further operative to compute delay measures for a plurality of packets includes computing the delay measure for a given one of the packets as a difference between a current time and an arrival time of the given packet in a node of the communication network.

16. The apparatus of claim 14 wherein the plurality of packets comprise  $N$  packets, each associated with a corresponding one of  $N$  data flows and located in a head position in a corresponding one of  $N$  queues.

17. The apparatus of claim 16 wherein the link scheduler is further operative to select a packet from a head position of a  $j$ th one of the  $N$  queues, such that a function of a given weight  $\alpha_j$  and a given delay measure  $W_j$  is maximal among all such functions for  $j = 1, 2, \dots, N$ , where  $\alpha_j$  is one of a set of positive weights  $\alpha_1, \alpha_2, \dots, \alpha_N$ .

18. The apparatus of claim 17 wherein the function of the given weight and the given delay measure is  $W_j/\alpha_j$ .

19. The apparatus of claim 17 wherein the link scheduler is configured to meet a quality of service requirement specified in terms of a deadline  $T_i$  and an allowed deadline violation probability  $\delta_i$ .

20. The apparatus of claim 19 wherein each of the weights  $\alpha_i$  in the set of positive weights  $\alpha_1, \alpha_2, \dots, \alpha_N$  is given by  $\alpha_i = -T_i / \log \delta_i$ .

21. The apparatus of claim 19 wherein the quality of service requirement is specified by:

$$P(W_i > T_i) \leq \delta_i \quad \text{for } i = 1, \dots, N.$$

22. The apparatus of claim 16 wherein the link scheduler is further operative to select a packet from a head position of a  $j$ th one of the  $N$  queues, such that a function of a given weight  $\alpha_j$  and a given delay measure  $Q_j$  is maximal among all such functions for  $j = 1, 2, \dots, N$ , where  $\alpha_j$  is one of a set of positive weights  $\alpha_1, \alpha_2, \dots, \alpha_N$ , and  $Q_j$  is a queue length of the  $j$ th queue.

23. The apparatus of claim 22 wherein the function of the given weight and the given delay measure is  $Q_j / \alpha_j$ .

24. The apparatus of claim 22 wherein the link scheduler is configured to meet a quality of service requirement specified in terms of a maximum queue length  $H_i$  and an allowed queue length violation probability  $\delta_i$ .

25. The apparatus of claim 19 wherein each of the weights  $\alpha_i$  in the set of positive weights  $\alpha_1, \alpha_2, \dots, \alpha_N$  is given by  $\alpha_i = -H_i / \log \delta_i$ .

26. The apparatus of claim 19 wherein the quality of service requirement is specified by:

$$P(Q_i > H_i) \leq \delta_i \quad \text{for } i = 1, \dots, N.$$

27. An apparatus for use in scheduling data packets for transmission over a communication link in a network, the apparatus comprising:

a memory implementing a set of queues, each of at least a subset of the queues including at least one packet; and

5 a processor coupled to the memory and operative to compute delay measures for a plurality of packets including at least one packet from each of the at least a subset of the queues, and to select a given one of the plurality of packets for transmission based at least in part on a comparison of weighted versions of the computed delay measures, such that the selected packet is the packet having the largest weighted delay associated therewith.

10 28. A machine-readable medium storing one or more software programs for scheduling data packets for transmission over a communication link in a network, wherein the one or more programs when executed by a processor include:

15 a step for computing delay measures for a plurality of packets including at least one packet from each of a plurality of queues; and

a step for selecting a given one of the plurality of packets for transmission based at least in part on a comparison of weighted versions of the computed delay measures, such that the selected packet is the packet having the largest weighted delay associated therewith.